The Quiet Sun
at metric and decimetric wavelengths

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- Observing the Quiet Sun with the NRH
- Recent results
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  – Coronal holes' spectrum
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Scientific Context

Freq. range 100 - 1000 MHz: allows observation of the low and middle corona

absorbtion/emission : thermal free-free, $\alpha = \dfrac{\xi(n,T)n^2}{\nu^2 T^{3/2}\mu}$

propagation: refraction indice, $\mu = \sqrt{1 - 81\times 10^6 n/\nu^2}$

- At higher frequencies the corona is transparent.
- At lower frequencies, the corona becomes thick,

  => decrease of the contrast between different structures.
- The corona is well seen in the considered frequecy range,

  and : the lower the frequency, the higher the observed level.

New view of the solar corona:

The radio probes at different altitudes,

whereas the XUVs probe at different temperatures.

Observational Context

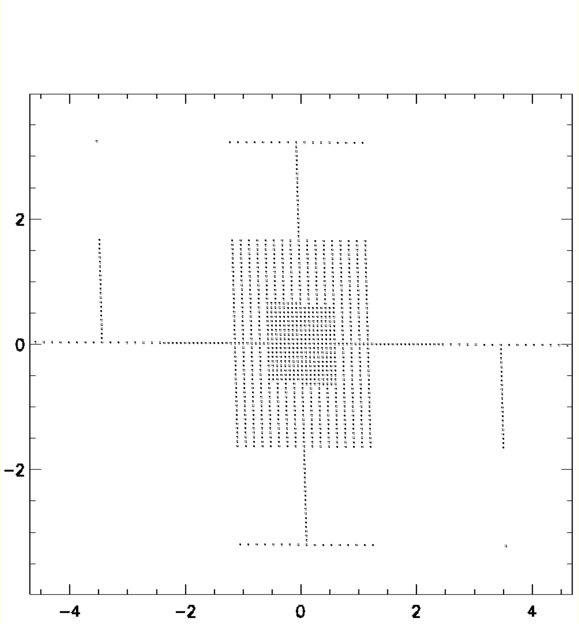
2D imaging instruments (i.e. 2D arrays) :

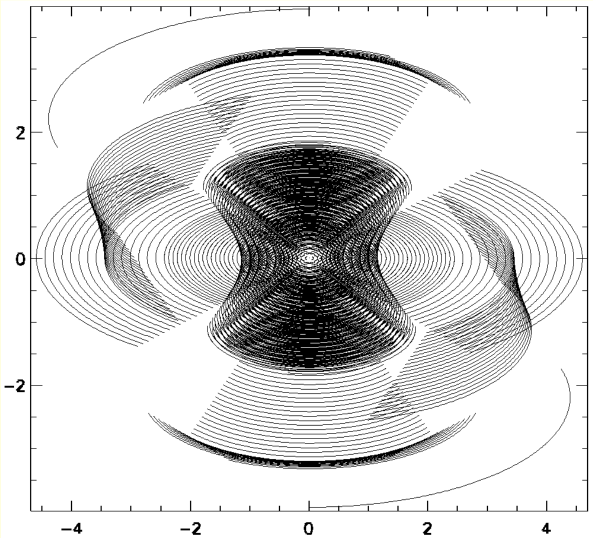
NRH	150 - 450 MHz,	(every day)
Culgoora	80 and 160	(in the past)
CLRO (Clark Lake)	~30 - 120	(-----------)
VLA	327 and 1420	(ocasionnally)
Gauribidanur	100	

Rotational Aperture Synthesis with the NRH

- The only way to get good high resolution images (quiet conditions)
- Improvements since Marqué, 2004: shorter baselines, 10 frequencies

Resolution	2	arc min	(at 432 MHz)	0.75	arc min
Field	48	--------		> 48	---------





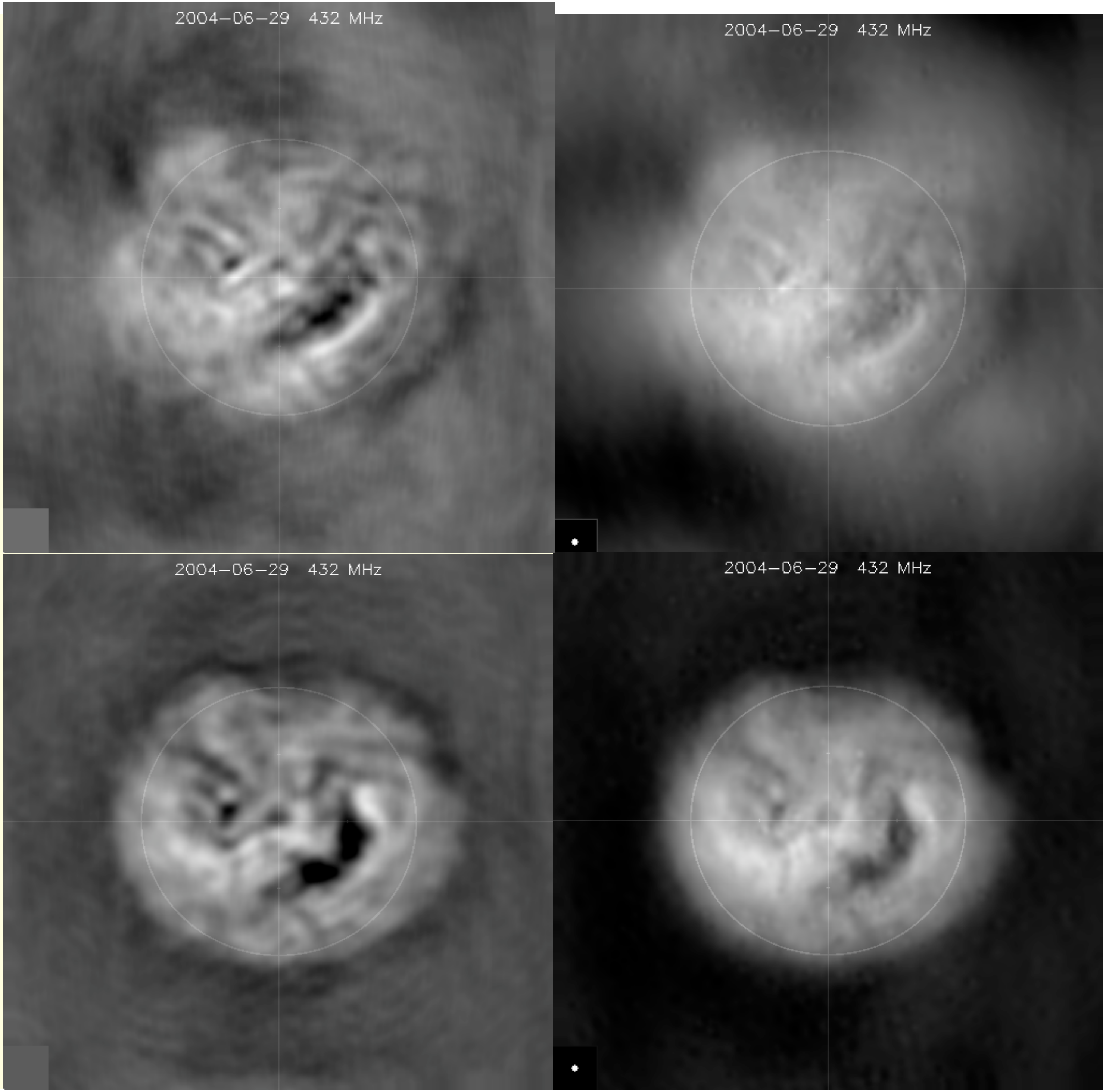
Units: 1000 / rad

However, the QS is a large and complex source

=> difficult deconvolution, sensitivity to calibration errors: Cygnus calib. unsufficient.

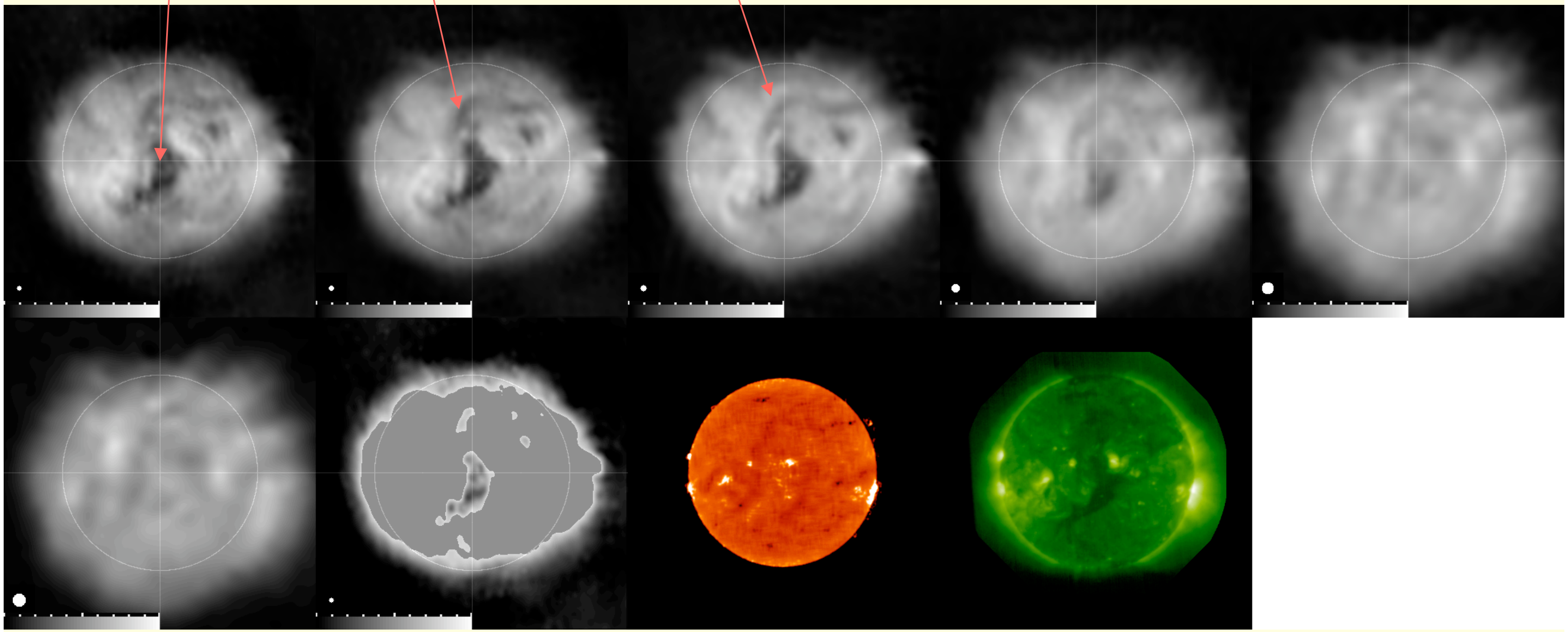
Cygnus calibration

Self calibration

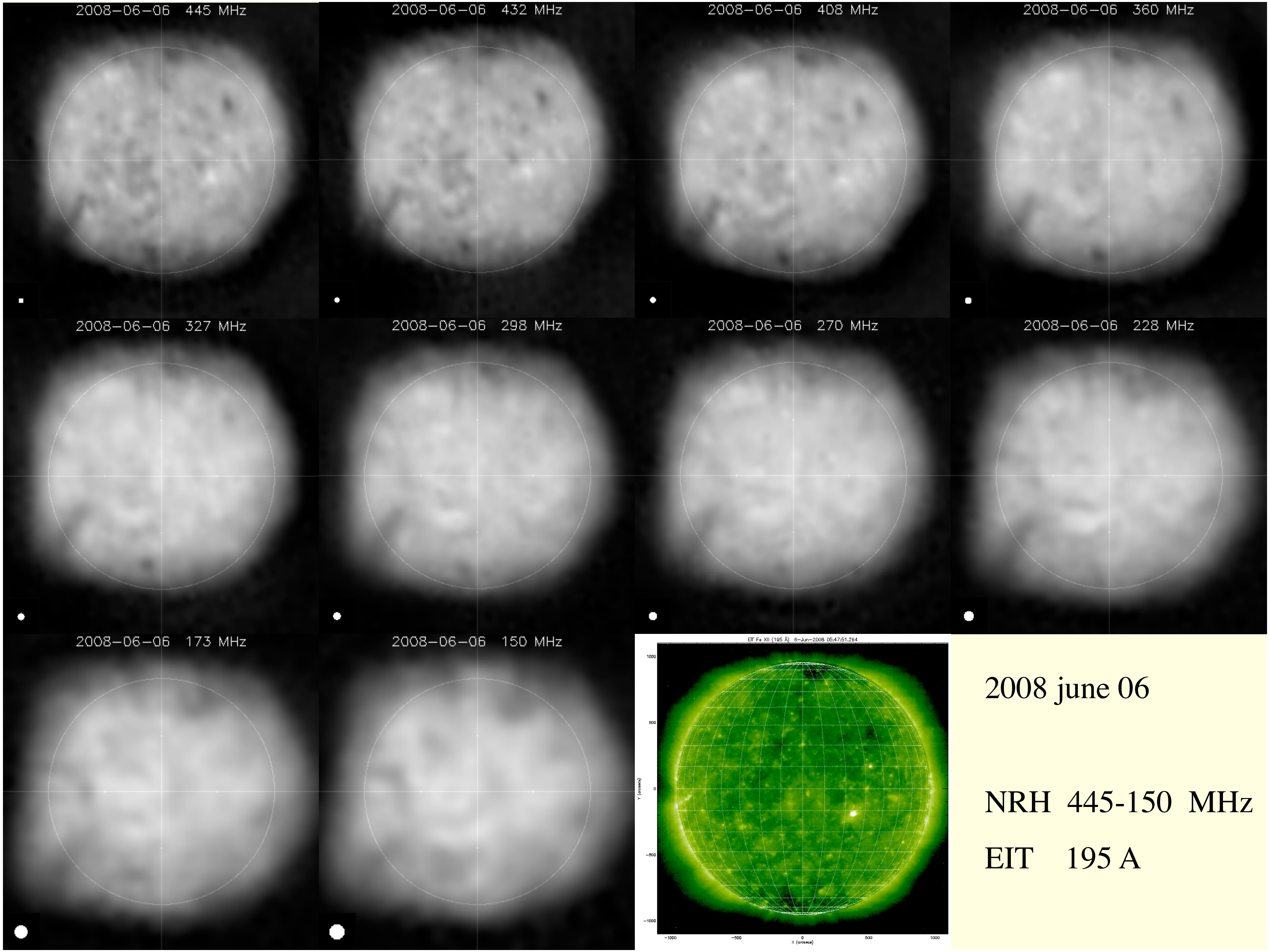


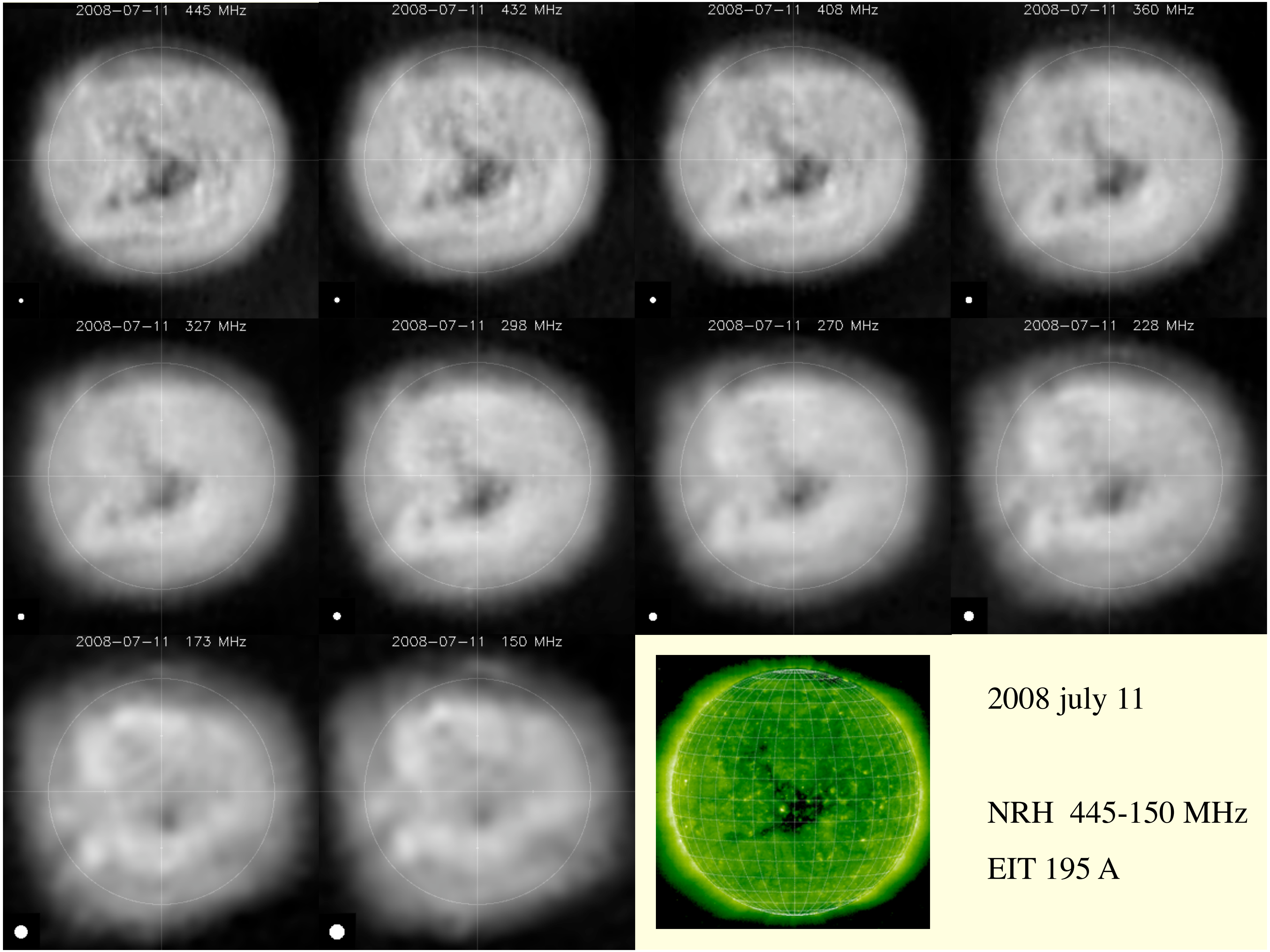
Recent Results / solar cycle declining phase

Coronal Hole   Dark Channel   Bright Ribbon   2004 june 27



NRH 432 - 150 MHz   Nobeyama   SoHo EIT 195 A


2008-06-06 445 MHz
2008-06-06 432 MHz
2008-06-06 408 MHz
2008-06-06 360 MHz
2008-06-06 327 MHz
2008-06-06 298 MHz
2008-06-06 270 MHz
2008-06-06 228 MHz
2008-06-06 173 MHz
2008-06-06 150 MHz
EIT Fe XII (195 Å) 6-Jun-2008 05:47:51.264
2008 june 06
NRH 445-150 MHz
EIT 195 A


2008-07-11 445 MHz
2008-07-11 432 MHz
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2008-07-11 298 MHz
2008-07-11 270 MHz
2008-07-11 228 MHz
2008-07-11 173 MHz
2008-07-11 150 MHz
2008 july 11
NRH 445-150 MHz
EIT 195 A

Recent Results

Sumary of morphological aspects

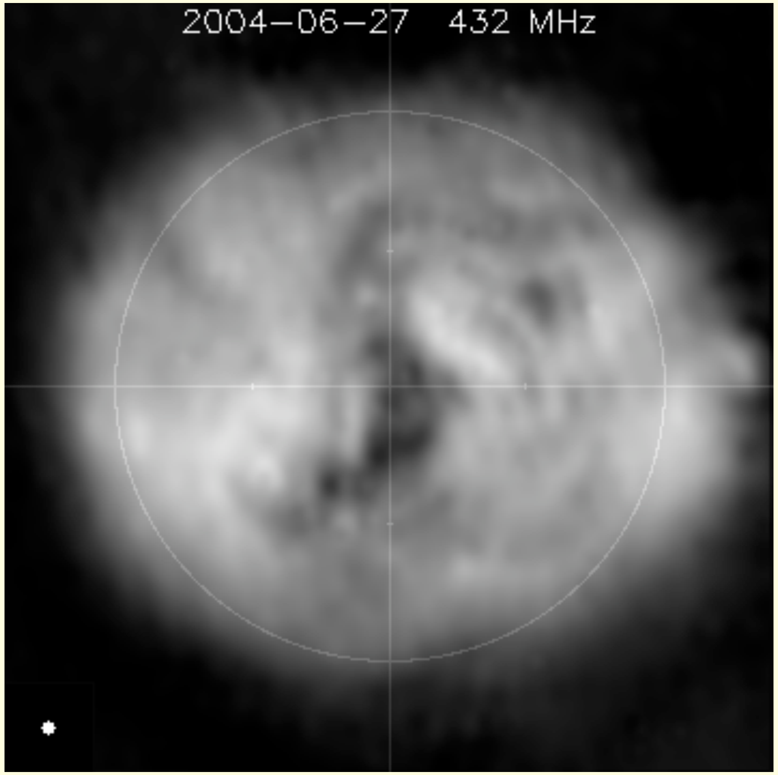
- Large scales structures :
  - Coronal holes, long dark channels, often aside bright ribbons
- Evident changes with altitude (i.e. with wavelength)
- Evolution with solar Cycle :
  - many short-lived (~ 1 day) small structures during minimum
- Coronal holes
  - appear very dark at high frequencies,
  - show internal small scale structure (≠ network)
  - and behave differently while crossing the disk (occultation ?)

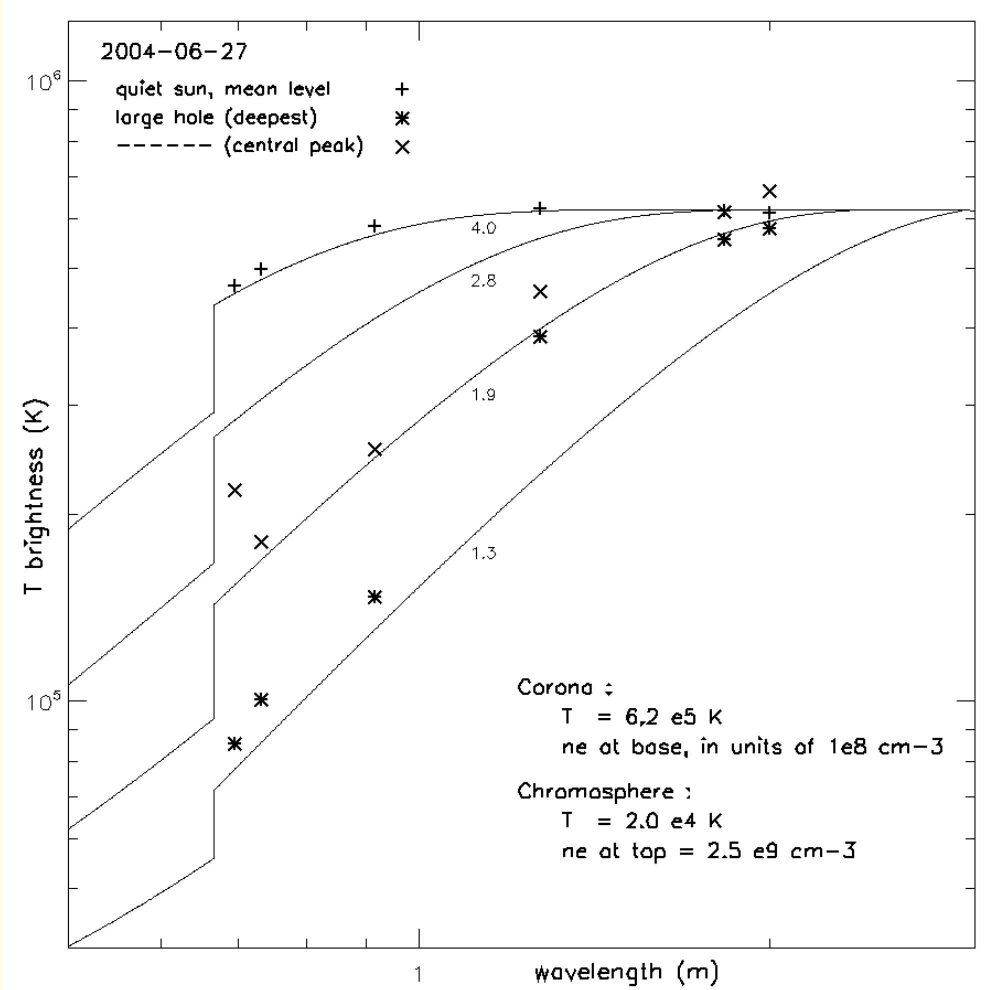
Recent Results / spectra

HF
$$T_B = T_{chrom} + T_{cor}\tau_{cor}$$
$$T_B = 2T_{cor}\tau_{cor}$$

BF
$$T_B = T_{cor}\exp(-2\tau_{cor})$$

Two-component model
Best fit: T = 6.2 e5 K, n = 1.3 e8 /cm3





Recent Results / spectra

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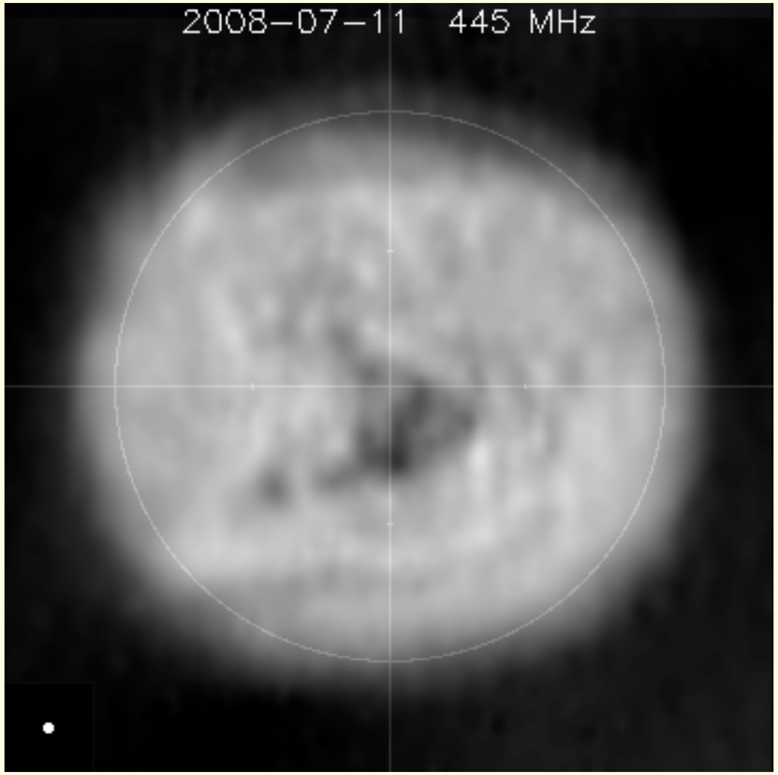
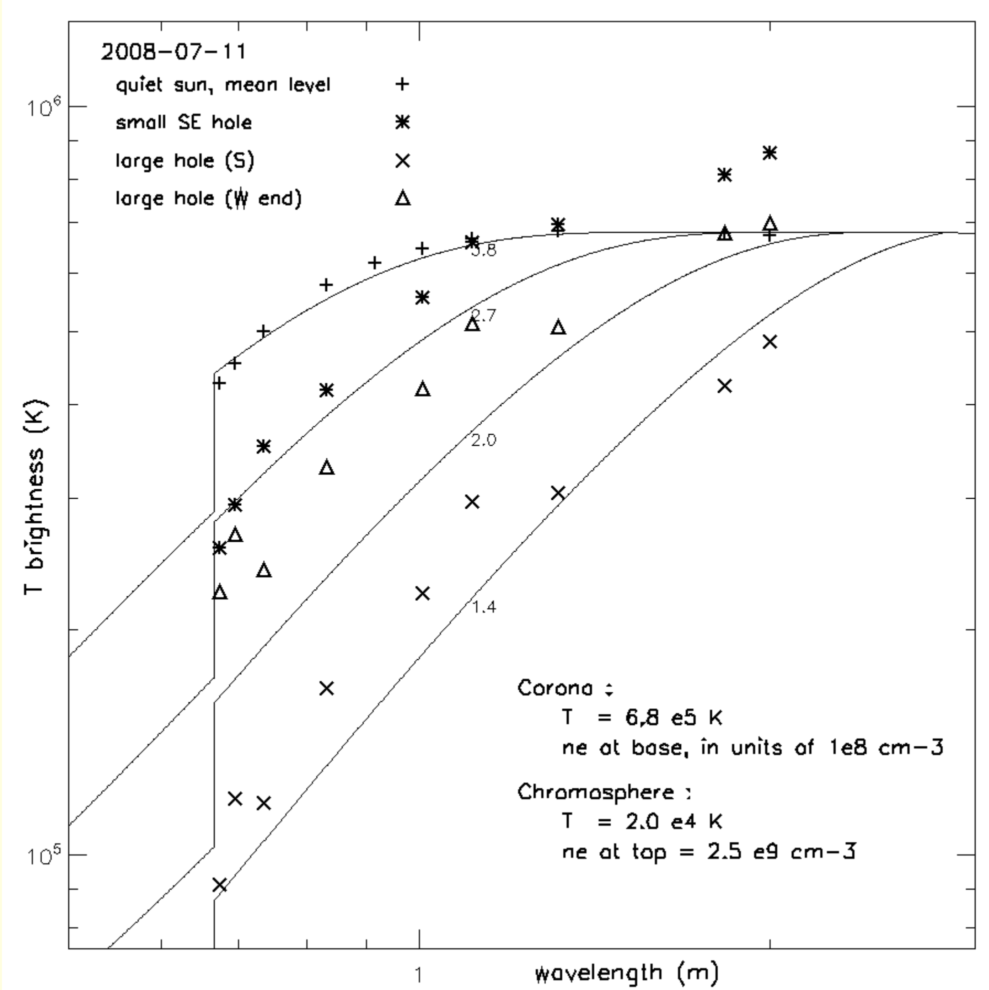
Two-component model
Best fit: T = 6.8 e5 K, n = 1.5 e8/cm3



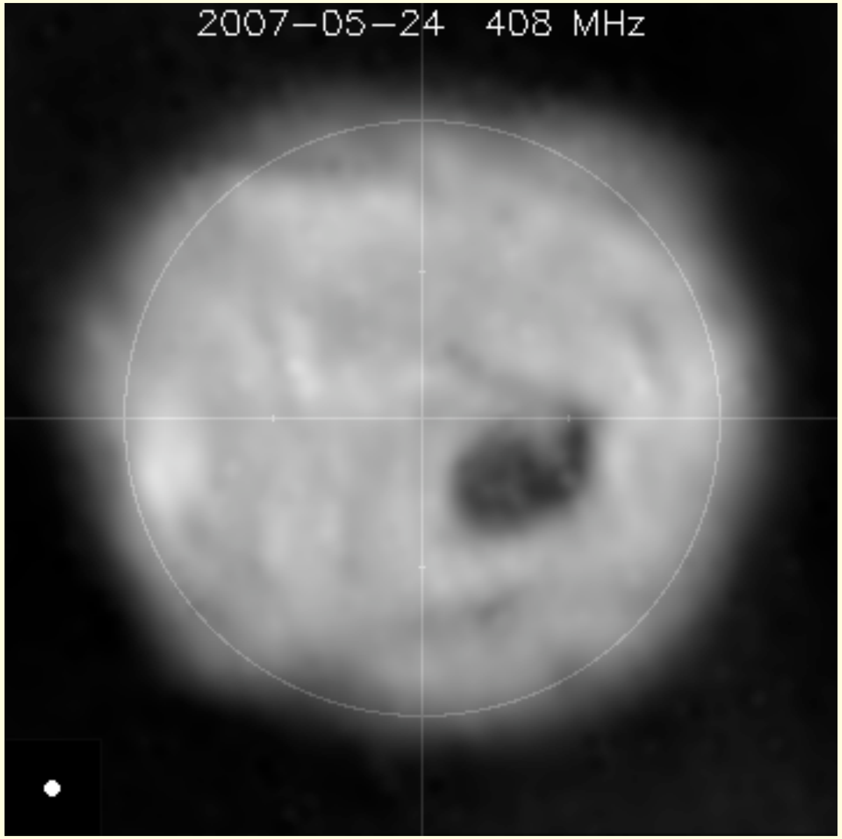


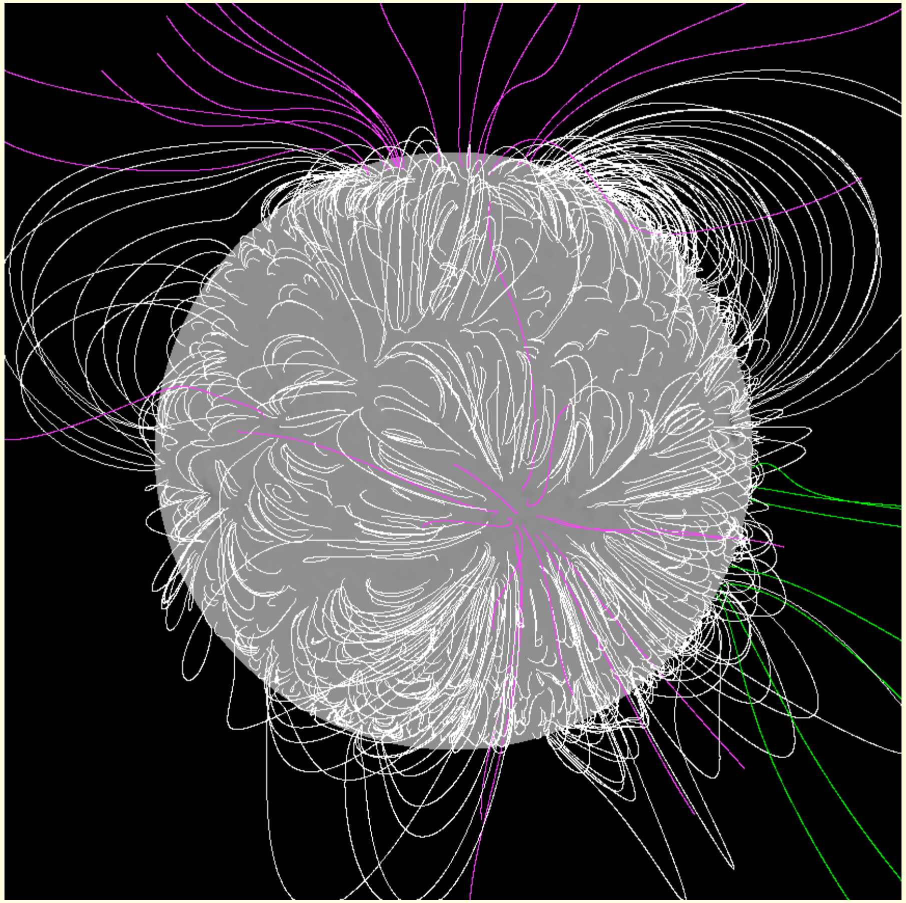
Perspective

- Understanding the large scale morphology
- Study of specific coronal structures
- Spectrum of equatorial coronal holes (compatibility with EUV models)
- Density profile over polar limbs
- Circular polarisation
- Joint NRH - GMRT observations
- Position of bursts relative to the radio coronal structures

Perspective / large scale morphology

Radio 408 MHz *vs* PFSS extrapolation





Perspective / spectrum of equatorial holes

Agreement between EUV and radio models ?
Last measurement with the NRH:

ν (MHz)	410	327	236	164	
Tb (kK)	360	580	640	<900	(CD et al, 1999 - snapshot images)
Tb (kK)	120	200	350	670	(M and C, 2009)

Difficult to inverse the radio spectrum *Tb(ν)* in order to get *T(z) and n(z)*
Conversely, use EUV models to compute radio spectrum and compare to the observed one:

$$n^2 \frac{dz}{dT} = DEM(T)$$

$$\frac{d(nT)}{nT} = -\frac{dz}{\eta T}$$

$\Rightarrow$ $T(z)$, $n(z)$ $\Rightarrow$ $Tb(\nu)$

- Large dispersion among the different *DEM* determinations from EUV- data / authors
- Need for simultaneous radio/EUV measurements

Perspective / density profile over polar limbs

At some distance over the limb, where refraction effects and optical thickness are small:

$$T_b = T\tau \propto T\frac{n^2}{\nu^2 T^{3/2}}L \propto \frac{n^2}{\nu^2}$$

- *Tb* does not depend anymore on *T*, only on *n*
- Two ways to obtain the density profile *n(z)*:
  - changing the line of sight
  - changing the observing frequency

Perspective / mapping of the circular polarisation

- Aim: to measure the magnetic field in equatorial coronal holes

- Gel'freikh (1972), Grebinskij et al (2000)
  For longitudinal field and optically thin amosphere :

$$P \propto \lambda \frac{d \log T_b}{d \log \lambda} B_l$$

- Borovik et al(1999) reported (Ratan, 1D array) :
  P = 3-4 % at 29 cm (1000 MHz)
  Bl up to 10 G

- => Good possibilities at 300 - 450 MHz

- However, our first attempt was not conclusive (contamination I/V)

Perspective / joint NRH - GMRT observations

- It is possible to combine NRH and GMRT observations due to:
  - Common frequencies (327, 236 MHz)
  - Overlap in observing time
  - Overlap in the *uv*-plane coverage

- Advantage:
  - The NRH has small baselines: QS imaging possible
  - The GMRT has long baselines: high resolution

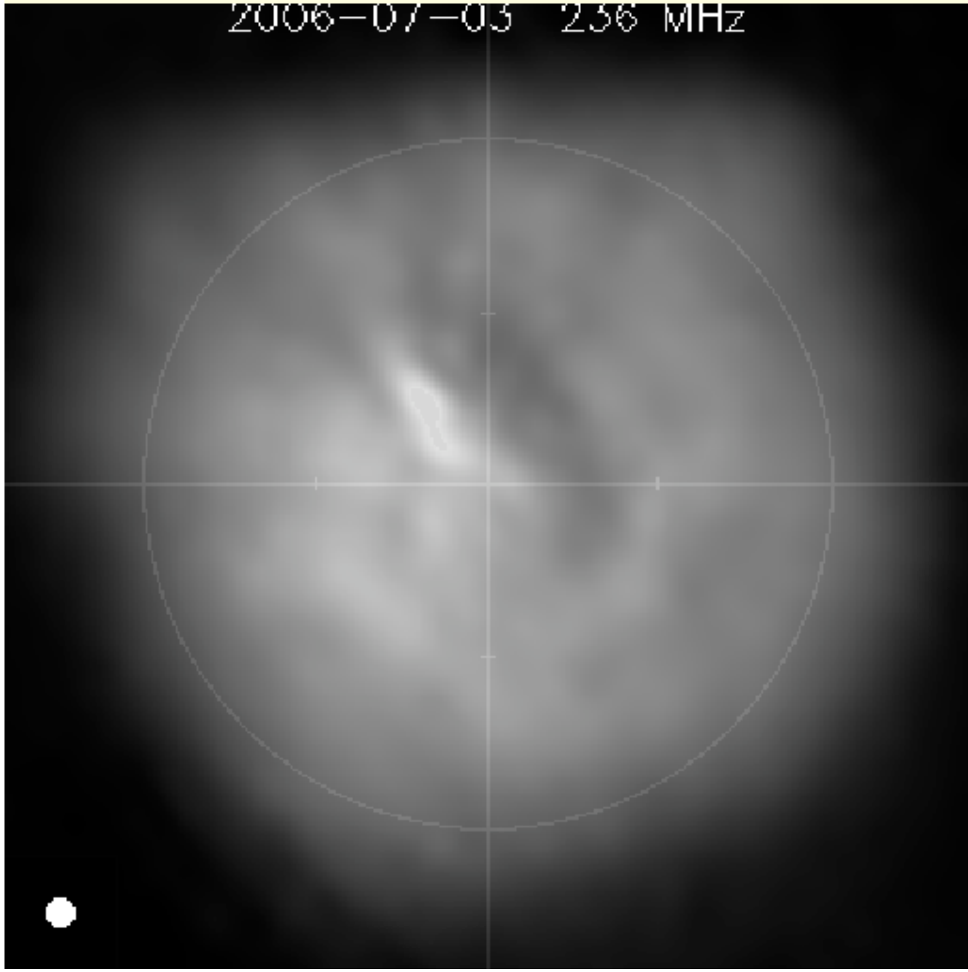
- Already done successfully (Mercier et al, 2006) for snapshot imaging of solar bursts

- A campaign of joint aperture synthesis observations has just started

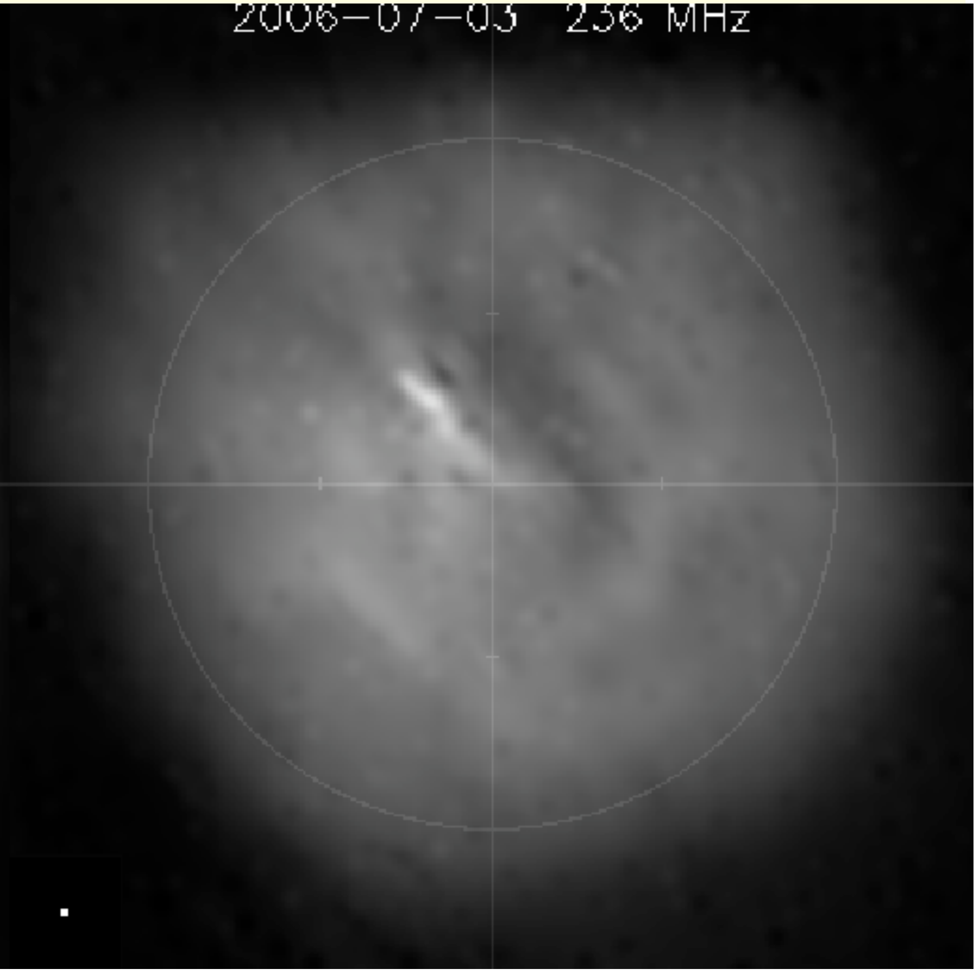
Perspective / joint NRH - GMRT observations

- First attempt to obtain a synthesis image from previous data

NRH alone



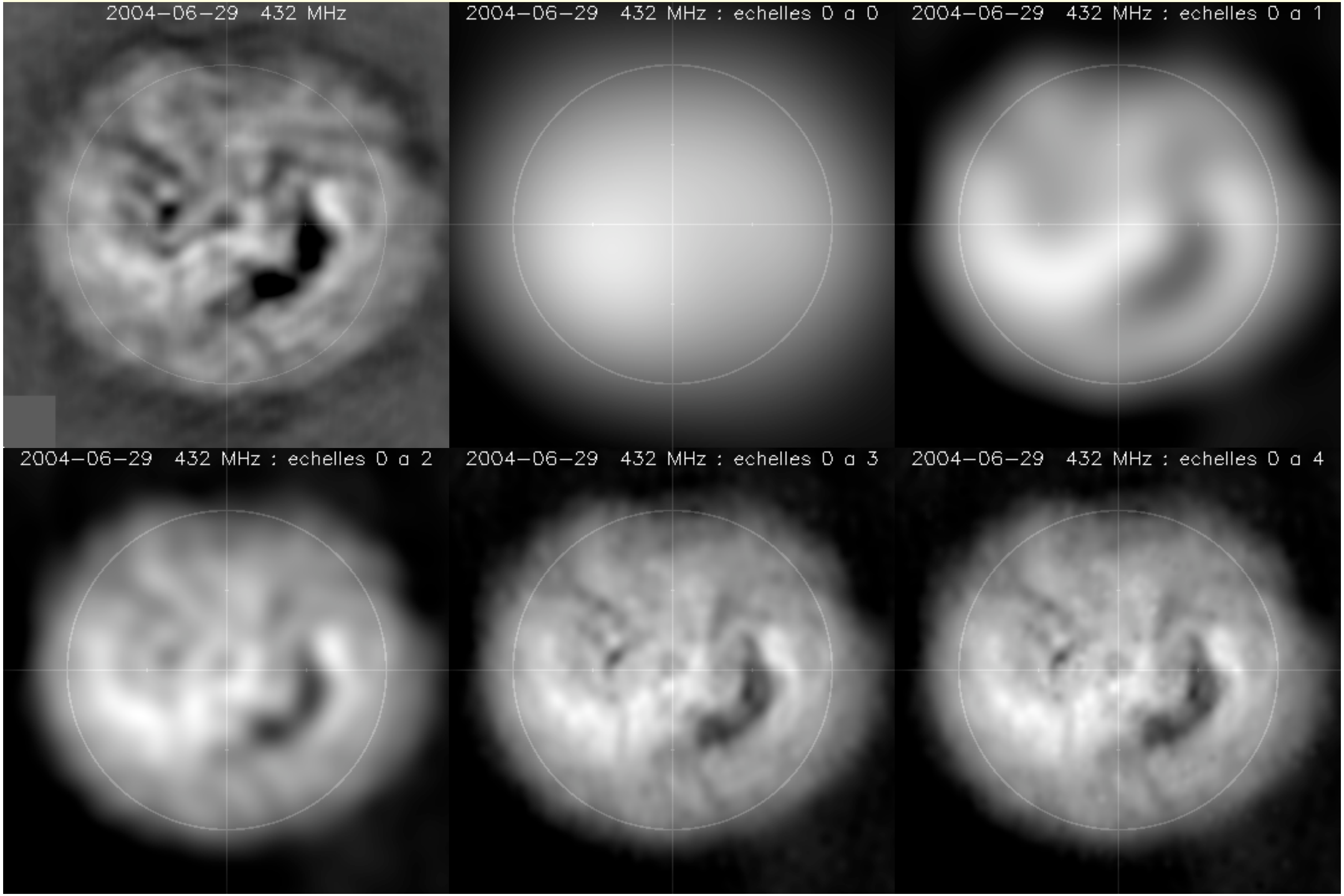
NRH + GMRT



Conclusions

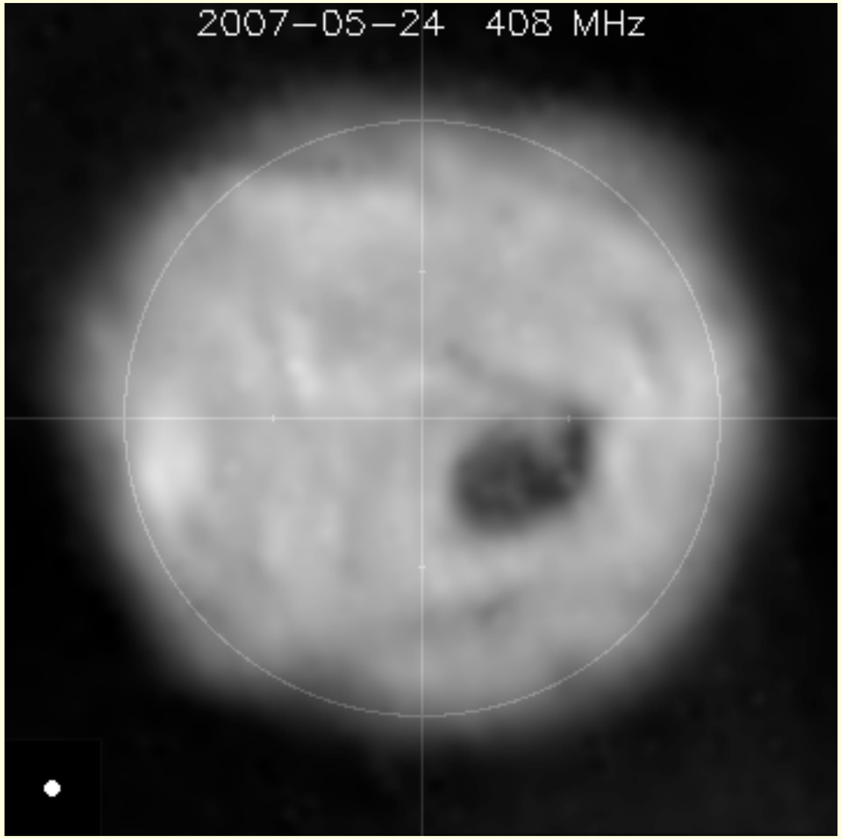
- We already have a large collection of data, starting from 2004
- Much work to be done
- Still improve the quality and reliability of the images
  - NRH operation
  - Data reduction

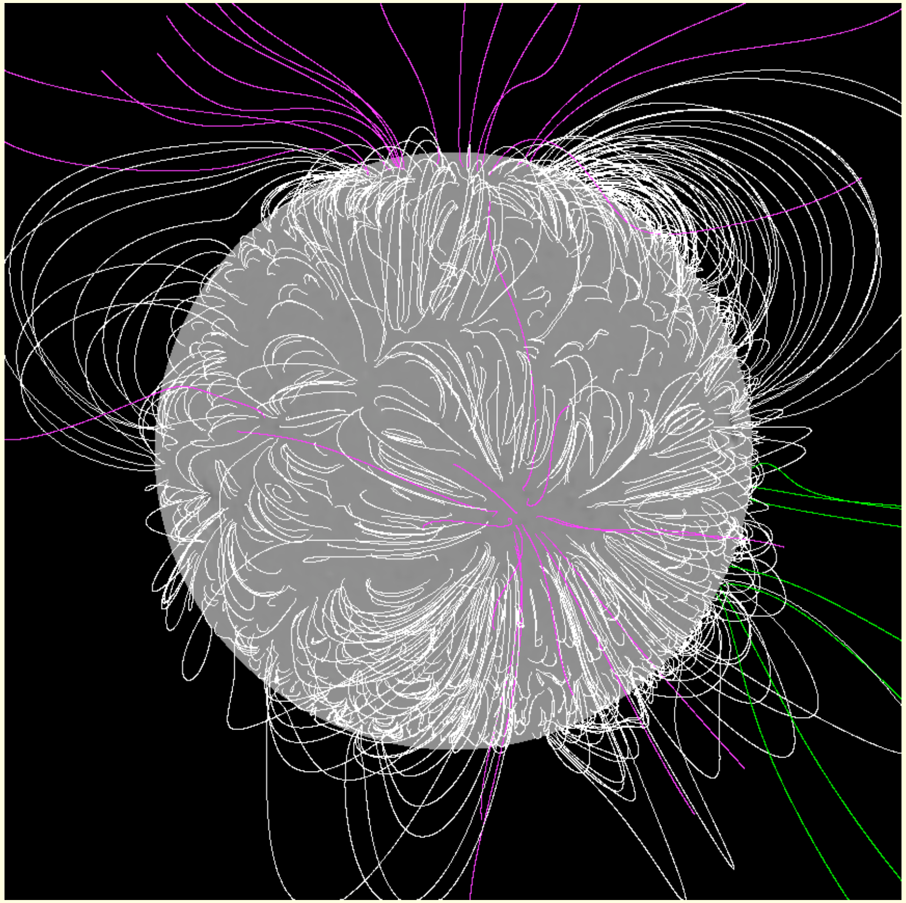
Rotational Synthesis with the NRH: multi -scale CLEAN



Perspective / large scale morphology

Radio 408 MHz *vs* PFSS extrapolation
2004/06/29 a faire





Perspective / large scale morphology

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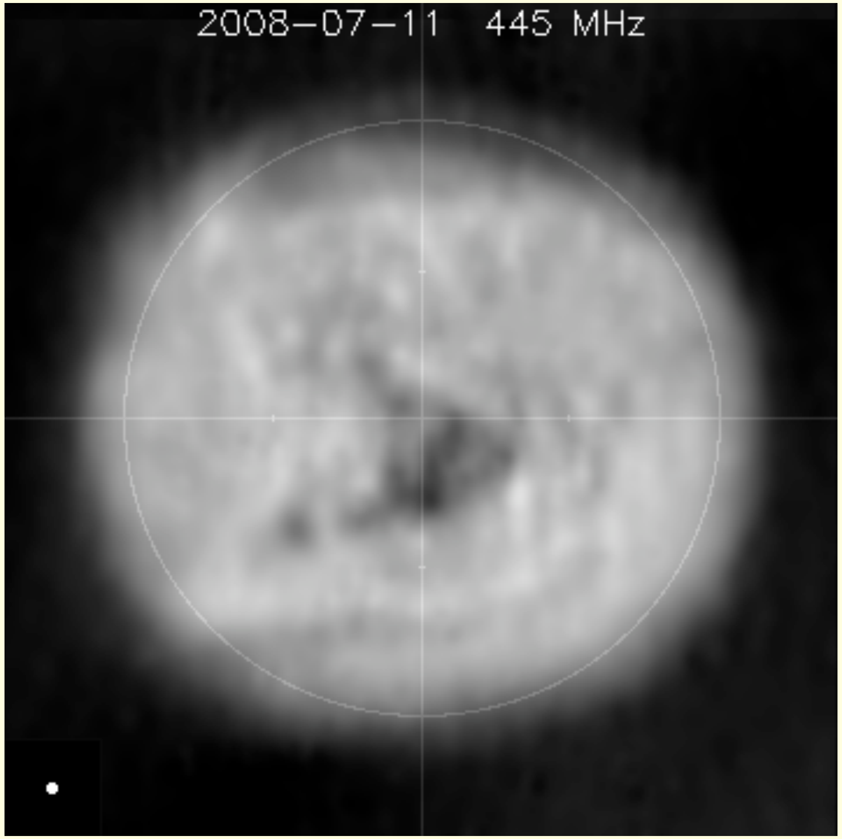

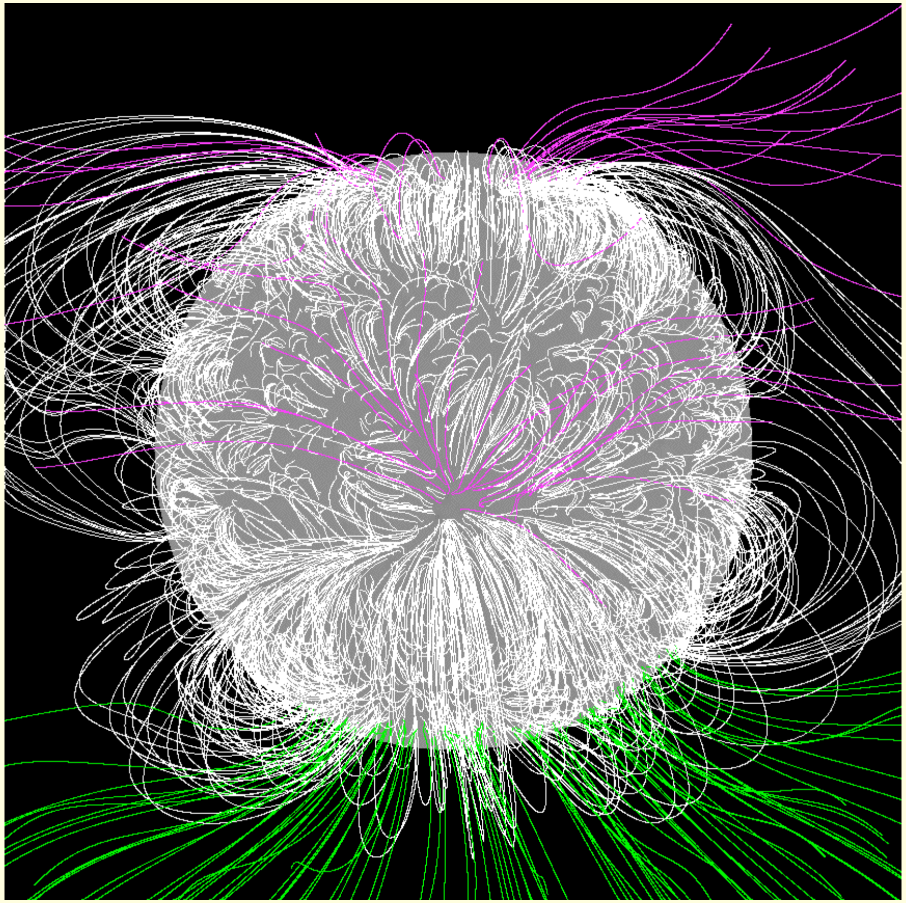

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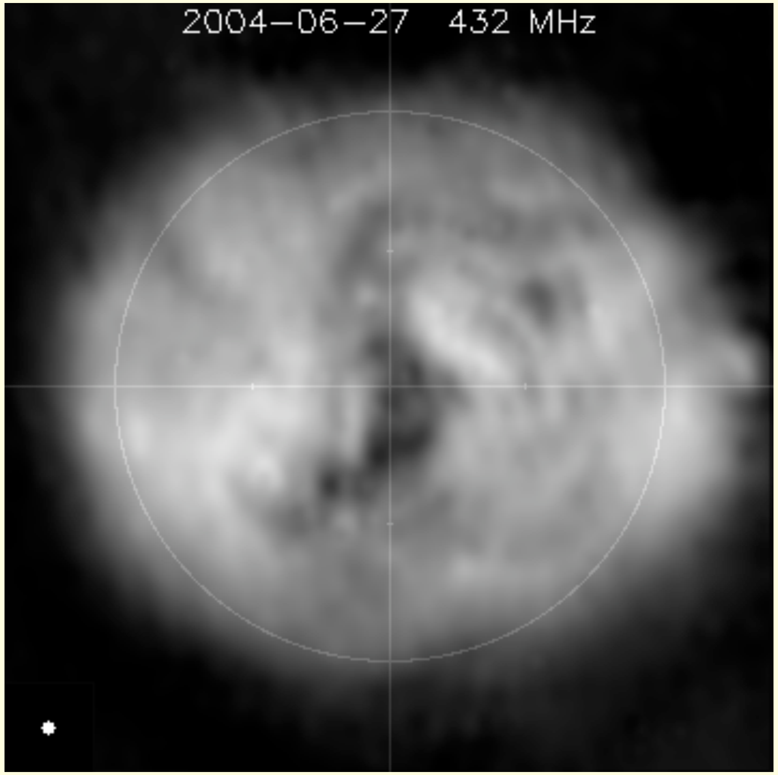

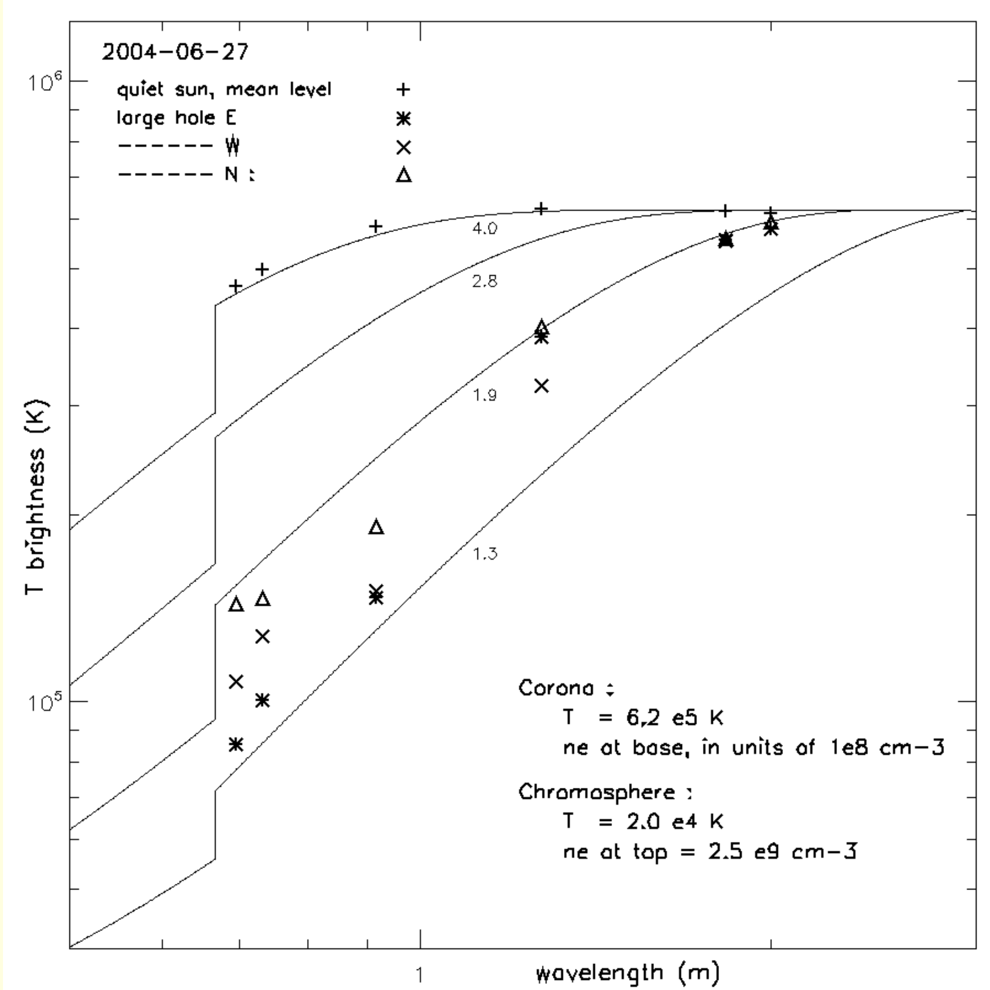

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